REVIEW ARTICLE

Total Ankle Replacement

Indications, Implant Designs, and Results

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SUMMARY

Background: About 1% of adults suffer from painful osteoarthritis of the ankle. The current literature contains no information on the percentage of such patients who derive long-term relief of symptoms from conservative treatment. Advanced ankle osteoarthritis can be treated with non-joint-preserving measures, such as total ankle replacement and ankle fusion.

Methods: This review is based on selected relevant publications, guidelines from Germany and abroad, and the authors' personal experience.

Results: Before surgery is considered, conservative measures such as physiotherapy and orthopedic aids should be used to the fullest possible extent. No randomized trials have yet been published comparing total ankle replacement with ankle fusion. Total ankle replacement with newer types of prosthesis yields good to very good intermediate-term and long-term results, with mean success rates of up to 90% at 10 years (range, 68–100%). Independent risk factors for the failure of ankle replacement are age over 70 years (odds ratio [OR] 3.84), primary osteoarthritis (OR 7.19), post-traumatic osteoarthritis (OR 6.2), and type of prosthesis (e.g., single hydroxyapatite coating: OR 15.04). The average range of motion of the replaced ankle joint is 25° to 30°, with values as high as 60°.

Conclusion: Total ankle replacement is a good treatment option for complete, end-stage ankle arthritis. It can restore joint function and make the patient mobile with little or no pain. There are, however, many contraindications to be taken into account. There is a need for further studies of the biomechanics of arthritic and replaced ankle joints and for long-term follow-up studies of total ankle replacement.

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Osteoarthritis of the ankle is an increasing issue in the healthcare sector (1, e1, e2). Approximately 1% of the adult population suffers from painful ankle osteoarthritis (2). The psychological and physical limitations associated with advanced ankle osteoarthritis are at least as marked as those of patients with osteoarthritis of the knee or hip (2). Degenerative changes of the ankle, in contrast to osteoarthritis of the knee or hip, are usually posttraumatic *(Table 1, eTable 1)* (3, e3, e4). Both poorly healed fractures to the lower extremity (4, e5) and repetitive ligament injuries (5) can play a major role. The main causes of secondary osteoarthritis of the ankle include rheumatic diseases, hemophilia, hemochromatosis, gout, avascular necrosis, and postinfectious states (1, e1).

This review article uses the current literature to explain the indications and the absolute and relative contraindications for total ankle replacement. It also presents the results of current clinical studies on postoperative functional outcomes and the probability of success of ankle replacement surgery.

Selective literature search

This review article is based on a selective literature search in established databases. The following medical databases were searched, with no date restriction: Medline, Cochrane, EmbaseTM, Cinahl, Google Scholar, ScienceDirect, and SpringerLink. The search terms used were the following: "total ankle replacement," "total ankle arthroplasty," "ankle replacement," "ankle arthroplasty," and "ankle prosthesis." All articles written in languages spoken by the authors (German, English, and French) were included.

The digital indices of the following orthopedic journals were also searched for the above-mentioned search terms: *Foot and Ankle International*; *Journal of Bone and Joint Surgery, American Volume*; *Bone & Joint Journal* (formerly known as the *Journal of Bone and Joint Surgery, British Volume*); *Clinical Orthopaedics and Related Research*; *Foot and Ankle Clinics of North America*; *Journal of Foot and Ankle Surgery*; and *Der Orthopäde*. In addition, the bibliographies of the identified original and review articles were searched for further studies.

The literature search was performed by two of the authors (AB and MDW), independently of each other.

TABLE 1

Etiology of advanced ankle osteoarthritis, based on a selection of clinical and epidemiological studies*

Study	Study type	Patients (ankles)	Etiology of ankle osteoarthritis, % (absolute values)		
			Primary	Secondary	Posttraumatic
(e6)	RS, SC, clinical	45 (51)	25.5% (13)	54.9% (28)	19.6% (10)
(6)	PS, SC, clinical	684 (722)	9.5% (69)	11.4% (82)	79.1% (571)
(e7)	PS, SC, clinical	47 (50)	6.0% (3)	8.0% (4)	86.0% (43)
(e8)	PS, SC, clinical	49 (50)	16.0% (8)	18.0% (9)	66.0% (33)
(e9)	PS, MC register, clinical	245 (257)	20.6% (53)	55.3% (142)	24.1% (62)
(e10)	PS, SC, clinical	80 (83)	33.7% (28)	25.3% (21)	41.0% (34)
(e11)	RS, SC, clinical	111 (123)	52.8% (65)	18.7% (23)	28.5% (35)
(e12)	RS, SC, clinical	61 (62)	19.4% (12)	4.8% (3)	75.8% (47)
(e13)	RS, SC, clinical	45 (52)	50.0% (26)	26.9% (14)	23.1% (12)
(e14)	RS, SC, clinical	126 (132)	46.2% (61)	25.0 (33)	28.8% (38)
(e15)	PS, SC, clinical	43 (50)	54.0% (27)	32.0% (16)	14.0% (7)
(e16)	PS, SC, clinical	396 (404)	16.6% (67)	13.6% (55)	69.8% (282)
(e17)	PS, SC, clinical	80 (84)	25.0% (21)	19.0% (16)	56.0% (47)
(e18)	PS, SC, clinical	82 (82)	34.2% (28)	13.4% (11)	52.4% (43)
(e19)	RS, SC, clinical	95 (100)	26.0% (26)	29.0% (29)	45.0% (45)
(e20)	PS, SC, clinical	229 (229)	13.8% (32)	4.0% (9)	82.2% (188)
(e21)	PS, SC, clinical	106 (106)	52.8% (56)	20.8% (22)	26.4% (28)
(e22)	PS, SC, clinical	233 (240)	30.8% (74)	17.9% (43)	51.3% (123)
(3)	PS, SC, epidemiological	639 (639)	7.2% (46)	23.2% (148)	69.6% (445)
(7)	PS, MC, clinical	593 (593)	26.5% (157)	15.3% (91)	58.2% (345)
(e23)	RS, SC, clinical	100 (100)	30.0% (30)	44.0% (44)	26.0% (26)
(e24)	RS, MC, clinical	501 (517)	13.9% (72)	25.9% (134)	60.2% (311)
(e25)	PS, MC register, clinical	515 (515)	19.2% (99)	59.2% (305)	21.6% (111)
(e26)	RS, SC, clinical	303 (306)	25.2% (77)	10.1% (31)	64.7% (198)
(e27)	RS, SC, clinical	103 (103)	71.8% (74)	18.5% (19)	9.7% (10)
(e28)	PS, SC, clinical	65 (68)	13.2% (9)	16.2% (11)	70.6% (48)
(e3)	RS, SC, epidemiological	390 (406)	8.9% (36)	12.8% (52)	78.3% (318)
(e29)	PS, SC, clinical	66 (66)	0.0% (0)	10.6% (7)	89.4% (59)
(e4)	RS, SC, clinical	226 (233)	5.6% (13)	23.2% (54)	71.2% (166)
(e30)	PS, SC, clinical	96 (100)	64.0% (64)	27.0% (27)	9.0% (9)
(e31)	RS, SC, clinical	90 (99)	40.4% (40)	12.1% (12)	47.5% (47)
Total/mean		6218 (6389)	21.5% (1373)	22.6% (1373)	56.0% (3575)

*Clinical (total ankle replacement) and epidemiological (etiology of ankle osteoarthritis) studies with at least 50 patients were included.
MC, multicenter; PS, prospective; RS, retrospective; SC, single-center

History and implant designs

Most first-generation ankle replacements performed in the 1970s and early 1980s were two-component cemented implants. The rate of aseptic loosening for all first-generation implant types was extremely high, occurring in almost 90% of implants (8).

Second-generation ankle implants (from the mid-1980s onwards) show improved implant shapes and better surgical technique: bone-conserving surgical approach and no cementation. Today there are several commercially available ankle implant types *(Figure 1)*. All implant designs can be classified by surgical technique and implant properties *(eTable 2)* (8).

Diagnosis and preoperative planning

A clinical and radiological diagnosis of osteoarthritis of the ankle can be made by the patient's treating

physician on the basis of clinical and radiological examination, as described.

The first step in preoperative diagnosis is to take a clinical history. All available documents should be evaluated: it is important to note which, if any, treatment options have already been administered. Further information such as BMI (body mass index), physical activity levels, previous and/or current treatment, severity of pain, limitations in everyday private and/or occupational activities, intake of analgesics, and concomitant diagnoses (diabetes mellitus, osteoporosis, polyneuropathy, etc.) should be recorded.

Clinical examination begins with examination of the foot/hindfoot on standing, sitting, and walking. Hindfoot alignment (valgus, varus, or neutral) is assessed from behind, with the patient standing. Stability is determined with the patient seated, using the talar tilt test (examination of medial and lateral ankle inversion) and the anterior drawer test (which tests for increased anterior translation of the talus) (9). Mobility of the subtalar joint is measured using a goniometer under load (10). Mobility of the ankle is measured manually, with the ankle fixed and free (e32).

Radiological examination includes conventional weight bearing radiographs: dorsoplantar and lateral views of the foot, anteroposterior (mortise) and lateral views of the ankle, and Saltzman view (hindfoot alignment view to assess inframalleolar alignment [11]) *(Figure 2)*. Supramalleolar alignment is determined using the of medial distal tibial angle (12, e33). In patients with knee deformities, a whole leg radiograph (orthoradiogram) is also taken. Optionally, computed tomography or magnetic resonance imaging may be performed; these can provide important additional information.

Indication for surgery

Conservative therapy should be administered before surgery is indicated. This includes intensive physiotherapy (local antiphlogistic therapy, muscle and movement exercises to prevent stiffness of the joint, muscle strength development, gait training) and possibly intra-articular hyaluronic acid viscosupplementation and orthopedic adaptation of footwear (13, 14).

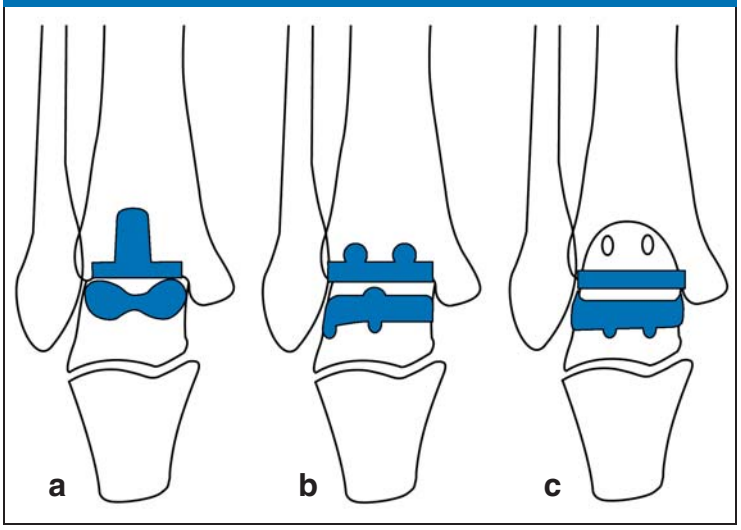
The ideal indication for total ankle replacement is advanced, complete osteoarthritis of the ankle (primary, secondary, or posttraumatic) with good bone quality, neutral alignment, good stability, and preserved mobility of the ankle. Further special indications include patients with bilateral osteoarthritis of the ankle (15, e34).

Total joint replacement can also be performed as revision arthroplasty in patients with failed ankle prosthesis (16, 17, e35). However, revision ankle arthroplasty, like revision joint replacement in general, is a technically demanding surgical procedure. Patients with painful non-union or malunion of previous ankle arthrodesis are another specific indication for total ankle replacement (18, e36, e37).

Absolute contraindications include acute or chronic infections, with or without osteomyelitis or osteitis; severe osteonecrosis of the talus (more than one third of the talus); neuromuscular diseases; neuroarthropathies (e.g. patients with Charcot foot); and patients with severe circulatory disorders (19). In patients with concomitant significant ligament instabilities and/or deformities that cannot be corrected intraoperatively, arthrodesis of the ankle should be performed instead of joint replacement. Metal allergies are also a contraindication (20, 21).

Relative contraindications include severe osteoporosis, poor bone quality (e.g. due to steroid treatment), diabetes mellitus, smoking, and excess weight, although the literature shows that good outcomes can be achieved in some of these cases [22]). There may be an increased rate of aseptic loosening of implant components in patients who engage in high levels of sporting activity (23, 24). Low-impact exercise (walking, swimming, cycling, golf), however, is recommended postoperatively (19, 24).

FIGURE 1



Modern ankle implant types
a) Components with tibial stem b) Components with bars c) Flat components

Surgical technique

An anterior approach is usually used for ankle replacement surgery *(eFigure 1)*. In patients with a history of previous ankle surgery, the surgical approach can be modified in order not to compromise postoperative wound healing (e38, e39). Depth preparation is performed beneath the tendon of the tibialis anterior muscle in order to preserve the anterior neurovascular bundle, which in most cases lies behind the tendon of the extensor hallucis longus muscle or between the tendons of the extensor hallucis longus and extensor digitorum longus muscles (e40). Bone resection is performed using an oscillating saw. Additional procedures for patients with concomitant deformities and/or instabilities should be performed after insertion of the implant components *(eTable 3)* (25, 26, e41, e42).

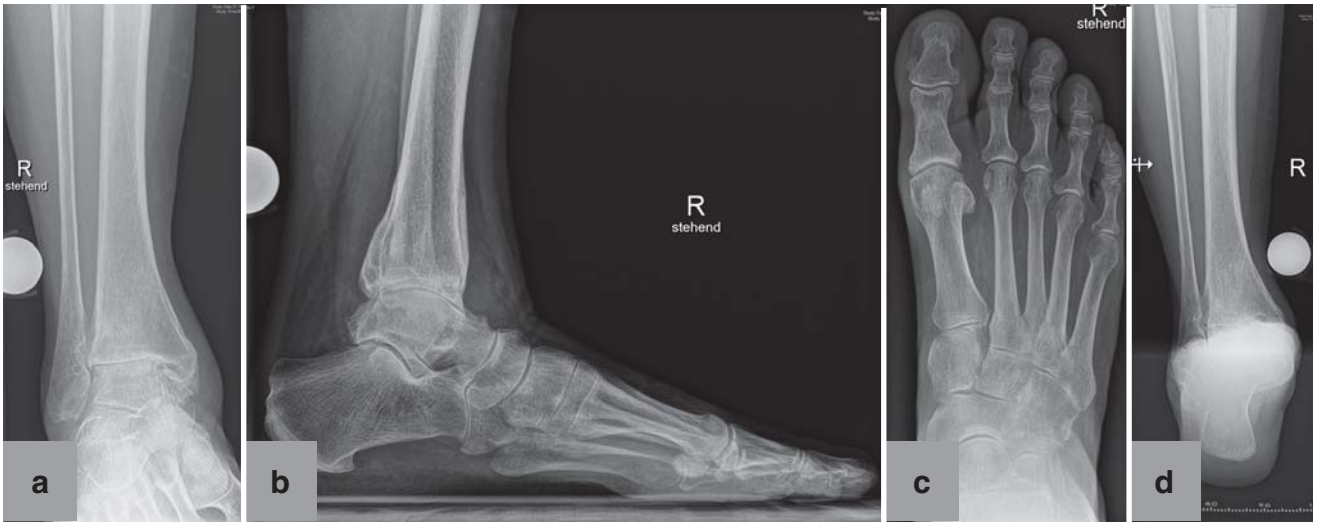


Figure 2: Preoperative conventional X-ray in standing position of 67-year-old female patient with posttraumatic ankle osteoarthritis following open reduction and internation fixation for trimalleolar luxation fracture 4 years earlier: a) mortise view of ankle; b) lateral view of foot and ankle; c) dorsoplantar view of foot; d) Saltzman view of hindfoot

Aftercare

We recommend immobilization using plaster cast of the lower leg or a stabilizing boot for six weeks after surgery. During this period full weight may be borne with the aid of two elbow crutches, depending on the severity of the patient's complaints. In patients with reduced bone quality and/or who have undergone additional procedures such as corrective osteotomy, we recommend 15 kg partial weightbearing for six weeks after surgery. Thromboprophylaxis is administered during immobilization (27). Clinical and radiological follow-up examination is performed after six weeks *(Figure 3)*. After this, intensive outpatient physiotherapy begins: gait training, proprioception exercises, gradual increase to full weightbearing, local antiphlogistic therapy including lymph drainage, active and passive ankle mobility therapy, extension exercises, and therapy to strengthen the triceps surae muscle.

Compression stockings are used for patients with persistent edema or soft-tissue swelling. The following sports can be recommended after full mobilization and full weightbearing ability have been attained: low-impact (e.g. walking, swimming, cycling, golf) or medium-impact (e.g. jogging, tennis, skiing) (24). Contact sports and sports that involve jumping should be avoided (24).

Clinical and radiological follow-up examinations are performed six weeks, three months, six months, and one year after surgery and then annually. The most important tools/questionnaires (28) that can be used to record functional postoperative outcomes following total ankle replacement are the American Orthopaedic Foot and Ankle Society (AOFAS) Ankle–Hindfoot Score (29) (score composed of pain, function, and alignment; minimum score, 0 points; maximum score, 100 points); and the Kofoed Ankle Score (e58) (score composed of pain, function, and range of motion; minimum score, 0 points; maximum score, 100 points). Pain level is determined using the visual analogue scale (VAS) from 0 (no pain) to 10 (worst possible pain) (e59). Quality of life can be analyzed using the SF-36 questionnaire (36-Item Short Form Health Survey) (e60).

Results/literature review

For a long time arthrodesis of the ankle was the first-line treatment for patients with advanced osteoarthritis of the ankle, which is not surprising given how uniformly disappointing the results of first-generation total ankle replacement were. Precise analysis of failures led to the development of new implant designs, acceptance of which is steadily increasing among orthopedic surgeons.

However, it is difficult to find well conducted, controlled, prospective studies in the literature, and in particular there are no comparisons of two-component and three-component implant types (30). Saltzman et al. (7) published the first results of a prospective study comparing ankle arthrodesis (66 cases) and total ankle replacement (593 patients) and demonstrated that patients with total ankle replacement had less pain and better functional outcomes postoperatively, with comparable postoperative complication rates. Although postoperative complications (poor wound healing, infections) were observed more frequently in patients undergoing ankle replacement than in those undergoing arthrodesis of the ankle—6.2% versus 1.5%— the difference was not statistically significant ($p = 0.087$). The Buechel–Pappas score (score composed of pain, function, deformity, and mobility; minimum score, 0 points; maximum score, 100 points) (e61) was used to assess functional outcome. Patients with total ankle

replacement had significantly better functional outcomes: Buechel–Pappas score 46.7 ± 13.0 versus 26.3 ± 17 (p<0.001). The two groups had comparable postoperative pain levels: 1.6 ± 1.8 versus 1.8 ± 2.0 (p = 0.607). Further studies are planned by the authors but have not yet been published (7).

Despite increasing acceptance, total ankle replacement remains a technically demanding procedure with a flat learning curve. Intraoperative complications are not uncommon; they include fractures of the medial and/or lateral malleolus in 0 to 23% of cases and tendon injuries (posterior tibial tendon, flexor hallucis longus, flexor digitorum longus) and nerve injuries (superficial/deep peroneal nerve) in 0 to 10% of cases (31, e62–e66). Difficult steps during surgery include correct component positioning, particularly of talar components (e62, e66). Incorrect tibial component positioning can be found in 0 to 16% of all cases, and incorrect talar component positioning in 0 to 36% of all cases (e62). Numerous *in vitro* biomechanical studies have shown that incorrect positioning of implant components has adverse biomechanical consequences such as reduced ankle mobility, pathological tension of the periarticular ligaments, and unfavorable intra-articular pressure distribution (e67–e70). We have shown in a clinical study that patients with suboptimal positioning of talar components have a higher rate of persisting pain and worse ankle mobility (32).

Postoperative outcomes following total ankle replacement are steadily improving *(Table 2; eTable 4)* but lag behind those of total knee and hip replacements *(Table 3)*. Labek et al. (33) investigated cumulative outcomes on the basis of worldwide joint replacement registers. Outcomes following total hip and knee replacements were comparable, with 1.29 and 1.26 revisions per 100 component years. This means that after 10 years 13 out of every 100 patients need to undergo revision surgery. The outcomes following medial partial replacement were somewhat worse, with 1.53 revisions per 100 component years. Total ankle replacement was associated with the worst outcomes, however, with 3.29 revisions per 100 component years, resulting in revision surgery for 33 out of every 100 patients within 10 years (33). The causes and frequency of failure of total ankle replacement are different from those of hip and knee replacements: the main causes of failure are aseptic loosening of tibial and/or talar components, persisting pain, and septic loosening *(Table 3)* (34).

In 2010, Gougoulias et al. (35) performed a systematic review of the literature including 13 level IV studies with a total of 1105 ankle replacements. Seven different implant types were used. The mean failure rate (defined as replacement of one or both implant components or implant removal and conversion to arthrodesis of the ankle) five years after implantation was 10%, but there was great variation in failure rates between different centers, ranging from 0% to 32%. The percentage of patients in the included studies with persisting complaints was between 27 and 60%.

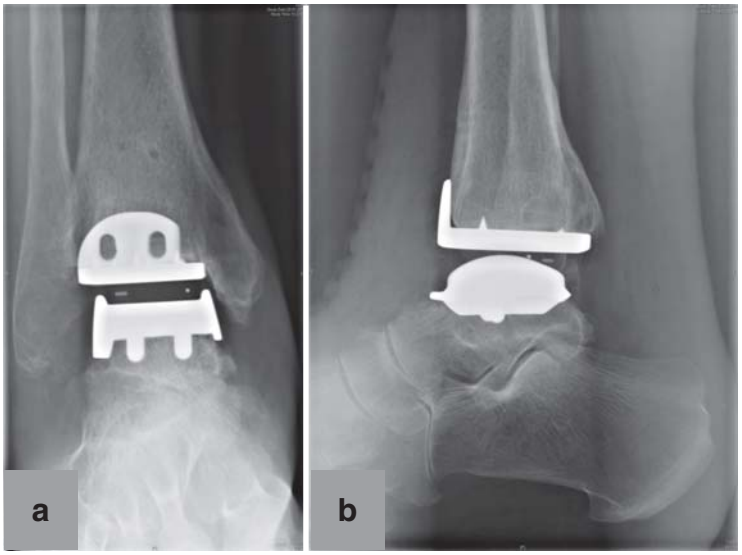


Figure 3: Postoperative X-ray of 67-year-old female patient 6 weeks after total ankle replacement: a) mortise view of ankle; b) lateral view of ankle

Postoperative improvement in ankle mobility was relatively low, with values between 0° and 14° (35). Zaidi et al. (36) published a systematic review of the literature and meta-analysis of 58 publications with a total of 7942 ankle replacements. The success rate after 10 years was 89%, with an annual failure rate of 1.2% (95% confidence interval [CI]: 0.7 to 1.6). The mean AOFAS Ankle–Hindfoot Score rose from 40 (95% CI: 36 to 43) preoperatively to 80 (95% CI: 76 to 84) postoperatively. The range of motion of the ankle on which surgery was performed improved from a mean of 23° (95% CI: 19 to 26°) preoperatively to 34° (95% CI: 26 to 41°) postoperatively (36).

We performed a survivorship analysis of implant components in 684 patients who received a total of 722 ankle replacements (6). The mean follow-up time in this prospective study was 6.3 ± 2.9 years. The probability of success of the implant components was 94% after five years and 84% after 10 years. These results are comparable with those of current clinical studies *(Table 2, eTable 4)*. The following factors were identified as independent risk factors for ankle replacement failure:

- Age under 70 years (odds ratio [OR]: 3.84)
- Etiology of ankle osteoarthritis (OR for primary osteoarthritis: 7.19; OR for posttraumatic osteoarthritis: 6.20)
- Implant generation (OR for single hydroxyapatite coating: OR: 15.04) (6).

For a long time a change of approach—removal of the implant components followed by arthrodesis—was the standard procedure in cases of ankle replacement failure. The current literature describes various surgical techniques and fixation methods for such arthrodesis after prosthesis removal: bone allografts, autografts, or replacement materials (e.g. porous metals such as

TABLE 2

Clinical outcomes following total ankle replacement: probability of survival of implant components*

Study	Study type	Implant type	No. of implants	Probability of survival of implant components
(e72)	RS, SC	Agility	207	76% after 9 years
(22)	RS, SC	HINTEGRA	123	93% after 6 years
(6)	PS, SC	HINTEGRA	722	94% after 5 years, 84% after 10 years
(e74)	RS, MC	Salto (388), AES (173), HINTEGRA (22), STAR (9)	592	88% after 71 months
(e79)	PS, SC	Buechel–Pappas (normal sulcus 40; deep sulcus 75)	115	74.2% (normal sulcus) after 20 years, 92% (deep sulcus) after 12 years
(e9)	PS, MC	STAR (216), TPR (32), HINTEGRA (6), AES (3)	257	89% after 5 years, 76% after 10 years
(e85)	PS, MC	BOX	158	96.1% after 4 years
(e86)	PS, MC	STAR (318), Buechel-Pappas (92), AES (69), HINTEGRA (29), Mobility (23)	531	78% after 5 years, 62% after 10 years
(e87)	PS, MC	STAR (322), Mobility (132), AES (115), Buechel-Pappas (109), CCI (66), HINTEGRA (36)	780	81% after 5 years, 69% after 10 years
(e11)	RS, SC	STAR	123	86% (patients with preoperative deformity up to 10°), 75% (patients with preoperative deformity 10 to 30°) after 5 years
(e88)	PS, MC	Agility (117), STAR (45), Mobility (29), Ramses (11)	202	86% after 5 years
(e90)	RS, SC	Mayo	204	79% after 5 years, 65% after 10 years, 61% after 15 years
(e14)	RS, SC	Agility	132	86% after 9 years, 63% after 11 years
(e92)	PS, SC	STAR	100	85.7% (patients under 50) and 91.6% (patients over 50) after 5 years, 75% (patients under 50) and 80.6% (patients over 50) after 10 years
(e96)	PS, MC	BOX	189	97% after 4 years
(e16)	PS, SC	INBONE (211), STAR (122), Salto-Talaris (71)	404	90% and 97.6% after 3.2 years with and without arthrodesis of the hindfoot
(21)	RS, MC	Salto (91), HINTEGRA (39), AES (20), Coppelia (17), STAR (11), Ramses (4), Akile (1)	183	86% (88.4% high-volume centers; 84.9% low-volume centers) after 5 years
(e22)	PS, SC	Mobility	240	97.7% after 4 years
(e102)	RS, SC	Salto	401	86.6% (all patients), 85.1% (posttraumatic osteoarthritis), 95.6% (rheumatoid arthritis), 87.9% (patients under 55) after 5 years
(e25)	PS, MC	AES (298), STAR (217)	515	83% after 5 years
(e26)	RS, SC	Agility	306	80% (89% in patients over 54) after 5 years
(e108)	PS, SC	STAR	200	92.7% after 5 years
(e109)	RS, MC	Salto	109	97.5% after 2 years
(e111)	PS, SC	STAR	200	93.3% after 5 years, 80.3% after 10 years
(e112)	PS, SC	Buechel-Pappas (100), STAR (100)	200	79% (Buechel-Pappas) and 95% (STAR) after 6 years
(e30)	PS, SC	Mobility	100	97% after 3 years, 93.6% after 4 years

*Clinical studies (total ankle replacement) with at least 100 patients were included.
AES: Ankle Evolutive System; BOX: Bologna–Oxford; MC: multicenter; PS: prospective; RS: retrospective; STAR: Scandinavian Total Ankle Replacement; TPR: Thomson, Prichard and Richard; SC: single-center

Trabecular Metal™) can be used to bridge the defect (37, 38, e113–e118). The alternative to converting to ankle arthrodesis is revision ankle arthroplasty (16, 17, e35, e119–e121). If possible, an implant type for which special revision components are available, e.g. a thicker metal plate for tibial components and larger weightbearing area and improved fixation for talar components, should be used. Revision surgery can be performed as one-stage or two-stage procedure. In the two-stage procedure, the goal of the first surgery is to address the bone defect. After bone integration of the autograft is achieved, the revision components can be implanted in a second surgery *(eFigure 2)*.

Conclusion

There is no gold standard treatment for advanced ankle osteoarthritis. Both, ankle arthrodesis and total ankle replacement are important treatment options in patients with end-stage ankle osteoarthritis. Attaining satisfactory intermediate-term and long-term postoperative outcomes in patients who have undergone total ankle replacement requires thorough preoperative examination and planning, taking careful account of all relative and absolute contraindications, with corresponding patient selection. If modern ankle implant designs are used, 10-year success rates of between 70 and 90% can be achieved.

TABLE 3

Most common causes of failure of total hip, knee, and ankle replacement (given in % according to Sadoghi et al. [34])

Cause of failure	Total hip replacement	Total knee replacement	Total ankle replacement
Aseptic loosening	55.2	29.8	38
Luxation/instability	11.8	6.2	8.5
Septic loosening	7.5	14.8	9.8
Periprosthetic fracture	6	3	2
Pathological wear	4.2	8.2	8
Persistent pain	3.7	9.5	12
Implant failure	2.5	4.7	5.3
Technical error	3.8	4.6	4.6

Conflict of interest statement
The authors declare that no conflict of interest exists.

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REFERENCES

1. Barg A, Pagenstert GI, Hugle T, et al.: Ankle osteoarthritis: etiology, diagnostics, and classification. Foot Ankle Clin 2013; 18: 411–26.
2. Glazebrook M, Daniels T, Younger A, et al.: Comparison of health-related quality of life between patients with end-stage ankle and hip arthrosis. J Bone Joint Surg Am 2008; 90: 499–505.
3. Saltzman CL, Salamon ML, Blanchard GM, Huff T, Hayes A, Buckwalter JA, et al.: Epidemiology of ankle arthritis: report of a consecutive series of 639 patients from a tertiary orthopaedic center. Iowa Orthop J 2005; 25: 44–6.
4. Goost H, Wimmer MD, Barg A, Kabir K, Valderrabano V, Burger C: Fractures of the ankle joint: investigation and treatment options. Dtsch Arztebl Int 2014; 111: 377–88.
5. Valderrabano V, Hintermann B, Horisberger M, Fung TS: Ligamentous posttraumatic ankle osteoarthritis. Am J Sports Med 2006; 34: 612–20.
6. Barg A, Zwicky L, Knupp M, Henninger HB, Hintermann B: HINTEGRA total ankle replacement: Survivorship analysis in 684 patients. J Bone Joint Surg Am 2013; 95: 1175–83.
7. Saltzman CL, Mann RA, Ahrens JE, et al.: Prospective controlled trial of STAR total ankle replacement versus ankle fusion: initial results. Foot Ankle Int 2009; 30: 579–96.
8. Barg A, Saltzman CL. Ankle replacement. In: Coughlin MJ, Saltzman CL, Anderson RB, (eds.): Mann´s surgery of the foot and ankle. 9th ed. Philadelphia: Elsevier Saunders, 2014; 1078–162.
9. Phisitkul P, Chaichankul C, Sripongsai R, Prasitdamrong I, Tengtrakulcharoen P, Suarchawaratana S: Accuracy of anterolateral drawer test in lateral ankle instability: a cadaveric study. Foot Ankle Int 2009; 30: 690–5.
10. Lindsjo U, Danckwardt-Lilliestrom G, Sahlstedt B: Measurement of the motion range in the loaded ankle. Clin Orthop Relat Res 1985; 199: 68–71.
11. Saltzman CL, el Khoury GY: The hindfoot alignment view. Foot Ankle Int 1995; 16: 572–6.
12. Barg A, Harris MD, Henninger HB, et al.: Medial distal tibial angle: comparison between weightbearing mortise view and hindfoot alignment view. Foot Ankle Int 2012; 33: 655–61.
13. Schmid T, Krause FG: Conservative treatment of asymmetric ankle osteoarthritis. Foot Ankle Clin 2013; 18: 437–48.
14. Barg A, Smirnov E, Paul J, Pagenstert G, Valderrabano V: Management der Sprunggelenksarthrose. Orthopadie Rheuma 2013; 16: 44–50.
15. Barg A, Knupp M, Hintermann B: Simultaneous bilateral versus unilateral total ankle replacement: A patient-based comparison of pain relief, quality of life and functional outcome. J Bone Joint Surg Br 2010; 92: 1659–63.
16. Hintermann B, Barg A, Knupp M: Revisionsarthroplastik des oberen Sprunggelenks. Orthopade 2011; 40: 1000–7.
17. Hintermann B, Zwicky L, Knupp M, Henninger HB, Barg A: HINTEGRA revision arthroplasty for failed total ankle prostheses. J Bone Joint Surg Am 2013; 95: 1166–74.
18. Hintermann B, Barg A, Knupp M, Valderrabano V: Conversion of painful ankle arthrodesis to total ankle arthroplasty. J Bone Joint Surg Am 2009; 91: 850–8.
19. Barg A, Knupp M, Henninger HB, Zwicky L, Hintermann B: Total ankle replacement using HINTEGRA, an unconstrained, three-component system: Surgical technique and pitfalls. Foot Ankle Clin 2012; 17: 607–35.
20. Ajis A, Henriquez H, Myerson M: Postoperative range of motion trends following total ankle arthroplasty. Foot Ankle Int 2013; 34: 645–56.
21. Pinar N, Vernet E, Bizot P, Brilhault J: Total ankle arthroplasty – total ankle arthroplasty in Western France: Influence of volume on complications and clinical outcome. Orthop Traumatol Surg Res 2012; 98: 26–30.

22. Barg A, Knupp M, Anderson AE, Hintermann B: Total ankle replacement in obese patients: component stability, weight change, and functional outcome in 118 consecutive patients. Foot Ankle Int 2011; 32: 925–32.

23. Naal FD, Impellizzeri FM, Loibl M, Huber M, Rippstein PF: Habitual physical activity and sports participation after total ankle arthroplasty. Am J Sports Med 2009; 37: 95–102.

24. Valderrabano V, Pagenstert G, Horisberger M, Knupp M, Hintermann B: Sports and recreation activity of ankle arthritis patients before and after total ankle replacement. Am J Sports Med 2006; 34: 993–9.

25. Valderrabano V, Frigg A, Leumann A, Horisberger M: Sprunggelenkprothese bei Valgusarthrose. Orthopade 2011; 40: 971–7.

26. Knupp M, Bolliger L, Barg A, Hintermann B: Sprunggelenkprothese bei Varusarthrose. Orthopade 2011; 40: 964–70.

27. Barg A, Henninger HB, Hintermann B: Risk factors for symptomatic deep-vein thrombosis in patients after total ankle replacement who received routine chemical thromboprophylaxis. J Bone Joint Surg Br 2011; 93: 921–7.

28. Naal FD, Impellizzeri FM, Rippstein PF: Which are the most frequently used outcome instruments in studies on total ankle arthroplasty? Clin Orthop Relat Res 2010; 468: 815–26.

29. Kitaoka HB, Alexander IJ, Adelaar RS, Nunley JA, Myerson MS, Sanders M: Clinical rating systems for the ankle-hindfoot, midfoot, hallux, and lesser toes. Foot Ankle Int 1994; 15: 349–53.

30. Valderrabano V, Pagenstert GI, Muller AM, Paul J, Henninger HB, Barg A: Mobile- and fixed-bearing total ankle prostheses: is there really a difference? Foot Ankle Clin 2012; 17: 565–85.

31. Saltzman CL, Amendola A, Anderson R, et al.: Surgeon training and complications in total ankle arthroplasty. Foot Ankle Int 2003; 24: 514–8.

32. Barg A, Elsner A, Anderson AE, Hintermann B: The effect of three-component total ankle replacement malalignment on clinical outcome: pain relief and functional outcome in 317 consecutive patients. J Bone Joint Surg Am 2011; 93: 1969–78.

33. Labek G, Thaler M, Janda W, Agreiter M, Stockl B: Revision rates after total joint replacement: cumulative results from worldwide joint register datasets. J Bone Joint Surg Br 2011; 93: 293–7.

34. Sadoghi P, Liebensteiner M, Agreiter M, Leithner A, Bohler N, Labek G: Revision surgery after total joint arthroplasty: a complication-based analysis using worldwide arthroplasty registers. J Arthroplasty 2013; 28: 1329–32.

35. Gougoulias N, Khanna A, Maffulli N: How successful are current ankle replacements? A systematic review of the literature. Clin Orthop Relat Res 2010; 468: 199–208.

36. Zaidi R, Cro S, Gurusamy K, et al.: The outcome of total ankle replacement: A systematic review and meta-analysis. Bone Joint J 2013; 95: 1500–7.

37. Hopgood P, Kumar R, Wood PL: Ankle arthrodesis for failed total ankle replacement. J Bone Joint Surg Br 2006; 88: 1032–8.

38. Culpan P, Le Strat V, Piriou P, Judet T: Arthrodesis after failed total ankle replacement. J Bone Joint Surg Br 2007; 89: 1178–83.

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For eReferences please refer to:
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eTables and eFigures:
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REVIEW ARTICLE

Total Ankle Replacement

Indications, Implant Designs, and Results

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eREFERENCES

e1. Egloff C, Gloyer M, Barg K, et al.: Arthrose des oberen Sprunggelenks – Ätiologie und Biomechanik. Fuss Sprungg 2013; 11: 179–85.

e2. Egloff C, Hugle T, Valderrabano V: Biomechanics and pathomechanisms of osteoarthritis. Swiss Med Wkly 2012; 142: 0.

e3. Valderrabano V, Horisberger M, Russell I, Dougall H, Hintermann B: Etiology of ankle osteoarthritis. Clin Orthop Relat Res 2009; 467: 1800–6.

e4. Wang B, Saltzman CL, Chalayon O, Barg A: Does the subtalar joint compensate for ankle malalignment in end-stage ankle arthritis? Clin Orthop Relat Res 2014; 473: 318–25.

e5. Horisberger M, Valderrabano V, Hintermann B: Posttraumatic ankle osteoarthritis after ankle-related fractures. J Orthop Trauma 2009; 23: 60–7.

e6. Anderson T, Montgomery F, Carlsson A: Uncemented STAR total ankle prostheses. Three to eight-year follow-up of fifty-one consecutive ankles. J Bone Joint Surg Am 2003; 85: 1321–9.

e7. Besse JL, Brito N, Lienhart C: Clinical evaluation and radiographic assessment of bone lysis of the AES total ankle replacement. Foot Ankle Int 2009; 30: 964–75.

e8. Buechel FF, Sr., Buechel FF, Jr., Pappas MJ: Ten-year evaluation of cementless Buechel-Pappas meniscal bearing total ankle replacement. Foot Ankle Int 2003; 24: 462–72.

e9. Fevang BT, Lie SA, Havelin LI, Brun JG, Skredderstuen A, Furnes O: 257 ankle arthroplasties performed in Norway between 1994 and 2005. Acta Orthop 2007; 78: 575–83.

e10. Hagena FW, Christ R, Kettrukat M: Die Endoprothese am oberen Sprunggelenk. Fuss Sprungg 2003; 1: 48–55.

e11. Hobson SA, Karantana A, Dhar S: Total ankle replacement in patients with significant pre-operative deformity of the hindfoot. J Bone Joint Surg Br 2009; 91: 481–6.

e12. Hurowitz EJ, Gould JS, Fleisig GS, Fowler R: Outcome analysis of agility total ankle replacement with prior adjunctive procedures: two to six year followup. Foot Ankle Int 2007; 28: 308–12.

e13. Karantana A, Hobson S, Dhar S: The Scandinavian total ankle replacement: Survivorship at 5 and 8 years comparable to other series. Clin Orthop Relat Res 2010; 468: 951–7.

e14. Knecht SI, Estin M, Callaghan JJ, et al.: The agility total ankle arthroplasty. Seven to sixteen-year follow-up. J Bone Joint Surg Am 2004; 86: 1161–71.

e15. Kumar A, Dhar S: Total ankle replacement: Early results during learning perios. Foot Ankle Surg 2007; 13: 19–23.

e16. Lewis JS, Jr., Adams SB, Jr., Queen RM, Deorio JK, Nunley JA, Easley ME: Outcomes after total ankle replacement in association with ipsilateral hindfoot arthrodesis. Foot Ankle Int 2014; 35: 535–42.

e17. Mann JA, Mann RA, Horton E: STAR ankle: Long-term results. Foot Ankle Int 2011; 32: 473–84.

e18. Nunley JA, Caputo AM, Easley ME, Cook C: Intermediate to long-term outcomes of the STAR total ankle replacement: The patient perspective. J Bone Joint Surg Am 2012; 94: 43–8.

e19. Pyevich MT, Saltzman CL, Callaghan JJ, Alvine FG: Total ankle arthroplasty: A unique design. Two to twelve-year follow-up. J Bone Joint Surg Am 1998; 80: 1410–20.

e20. Queen RM, Grier AJ, Butler RJ, et al.: The influence of concomitant triceps surae lengthening at the time of total ankle arthroplasty on postoperative outcomes. Foot Ankle Int 2014; 35: 863–70.

e21. Ramaskandhan JR, Kakwani R, Kometa S, Bettinson K, Siddique MS: Two-year outcomes of MOBILITY Total Ankle Replacement. J Bone Joint Surg Am 2014; 96: e53.

e22. Rippstein PF, Huber M, Coetzee JC, Naal FD: Total ankle replacement with use of a new three-component implant. J Bone Joint Surg Am 2011; 93: 1426–35.

e23. Schimmel JJ, Walschot LH, Louwerens JW: Comparison of the short-term results of the first and last 50 Scandinavian total ankle replacements: Assessment of the learning curve in a consecutive series. Foot Ankle Int 2014; 35: 326–33.

e24. Schuberth JM, Babu NS, Richey JM, Christensen JC: Gutter impingement after total ankle arthroplasty. Foot Ankle Int 2013; 34: 329–37.

e25. Skytta ET, Koivu H, Eskelinen A, Ikavalko M, Paavolainen P, Remes V: Total ankle replacement: A population-based study of 515 cases from the Finnish arthroplasty register. Acta Orthop 2010; 81: 114–8.

e26. Spirt AA, Assal M, Hansen ST, Jr.: Complications and failure after total ankle arthroplasty. J Bone Joint Surg Am 2004; 86: 1172–8.

e27. Sung KS, Ahn J, Lee KH, Chun TH: Short-term results of total ankle arthroplasty for end-stage ankle arthritis with severe varus deformity. Foot Ankle Int 2014; 35: 225–31.

e28. Valderrabano V, Hintermann B, Dick W: Scandinavian total ankle replacement: A 3.7-year average followup of 65 patients. Clin Orthop Relat Res 2004; 424: 47–56.

e29. Vienne P, Nothdurft P: OSG-Totalendoprothese Agility: Indikationen, Operationstechnik und Ergebnisse. Fuss Sprungg 2004; 2: 17–28.

e30. Wood PL, Karski MT, Watmough P: Total ankle replacement: The results of 100 mobility total ankle replacements. J Bone Joint Surg Br 2010; 92: 958–62.

e31. Yoon HS, Lee J, Choi WJ, Lee JW: Periprosthetic osteolysis after total ankle arthroplasty. Foot Ankle Int 2014; 35: 14–21.

e32. Taylor KF, Bojescul JA, Howard RS, Mizel MS, McHale KA: Measurement of isolated subtalar range of motion: a cadaver study. Foot Ankle Int 2001; 22: 426–32.

e33. Stufkens SA, Barg A, Bolliger L, Stucinskas J, Knupp M, Hintermann B: Measurement of the medial distal tibial angle. Foot Ankle Int 2011; 32: 288–93.

e34. Barg A, Henninger HB, Knupp M, Hintermann B: Simultaneous bilateral total ankle replacement using a 3-component prosthesis: Outcome in 26 patients followed for 2–10 years. Acta Orthop 2011; 82: 704–10.

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e35. Ellington JK, Gupta S, Myerson MS: Management of failures of total ankle replacement with the agility total ankle arthroplasty. J Bone Joint Surg Am 2013; 95: 2112–8.

e36. Hintermann B, Barg A, Knupp M, Valderrabano V: Conversion of painful ankle arthrodesis to total ankle arthroplasty. Surgical technique. J Bone Joint Surg Am 2010; 92: 55–66.

e37. Barg A, Hintermann B: Takedown of painful ankle fusion and total ankle replacement using a 3-component ankle prosthesis. Tech Foot & Ankle 2010; 9: 190–8.

e38. Amin A, Mahoney J, Daniels TR: Anteromedial approach for ankle arthoplasty and arthrodesis: technique tip. Foot Ankle Int 2012; 33: 1011–4.

e39. Bibbo C: A modified anterior approach to the ankle. J Foot Ankle Surg 2013; 52: 136–7.

e40. Solomon LB, Ferris L, Henneberg M: Anatomical study of the ankle with view to the anterior arthroscopic portals. ANZ J Surg 2006; 76: 932–6.

e41. Easley ME: Surgical treatment of the arthritic varus ankle. Foot Ankle Clin 2012; 17: 665–86.

e42. Barg A, Pagenstert GI, Leumann AG, Muller AM, Henninger HB, Valderrabano V: Treatment of the arthritic valgus ankle. Foot Ankle Clin 2012; 17: 647–63.

e43. Pagenstert G, Knupp M, Valderrabano V, Hintermann B: Realignment surgery for valgus ankle osteoarthritis. Oper Orthop Traumatol 2009; 21: 77–87.

e44. Barg A, Saltzman CL: Single-stage supramalleolar osteotomy for coronal plane deformity. Curr Rev Musculoskelet Med 2014; 7: 277–91.

e45. Barg A, Pagenstert GI, Horisberger M, et al.: Supramalleolar osteotomies for degenerative joint disease of the ankle joint: indication, technique and results. Int Orthop 2013; 37: 1683–95.

e46. Stufkens SA, Knupp M, Hintermann B: Medial displacement calcaneal osteotomy. Tech Foot & Ankle 2009; 8: 85–90.

e47. Hintermann B, Valderrabano V, Kundert HP: Lengthening of the lateral column and reconstruction of the medial soft tissue for treatment of acquired flatfoot deformity associated with insufficiency of the posterior tibial tendon. Foot Ankle Int 1999; 20: 622–9.

e48. Backus JD, McCormick JJ: Tendon transfers in the treatment of the adult flatfoot. Foot Ankle Clin 2014; 19: 29–48.

e49. Davies MB, Rosenfeld PF, Stavrou P, Saxby TS: A comprehensive review of subtalar arthrodesis. Foot Ankle Int 2007; 28: 295–7.

e50. Knupp M, Stufkens SA, Hintermann B: Triple arthrodesis. Foot Ankle Clin 2011; 16: 61–7.

e51. Hintermann B, Knupp M, Pagenstert GI: Deltoid ligament injuries: Diagnosis and management. Foot Ankle Clin 2006; 11: 625–37.

e52. Wimmer MD, Vavken P, Barg A, Valderrabano V, Pagenstert GI: Anatomic bundle reconstruction of the deltoid ligament. Sport Orthop Traumatol 2013; 29: 214–8.

e53. Knupp M, Pagenstert G, Valderrabano V, Hintermann B: Osteotomien zur Entlastung der Varusarthrose im oberen Sprunggelenk. Oper Orthop Traumatol 2008; 20: 262–73.

e54. Weseley MS, Barenfeld PA: Mechanism of the Dwyer calcaneal osteotomy. Clin Orthop Relat Res 1970; 70: 137–40.

e55. Knupp M, Horisberger M, Hintermann B: A new z-shaped calcaneal osteotomy for 3-plane correction of severe varus deformity of the hindfoot. Tech Foot & Ankle 2008; 7: 90–5.

e56. Valderrabano V, Wiewiorski M, Frigg A, Hintermann B, Leumann A: Direkte anatomische Rekonstruktion des lateralen Bandapparates bei chronischer lateraler Instabilität des oberen Sprunggelenks. Unfallchirurg 2007; 110: 701–4.

e57. Pagenstert GI, Hintermann B, Knupp M: Operative management of chronic ankle instability: Plantaris graft. Foot Ankle Clin 2006; 11: 567–83.

e58. Kofoed H: Cylindrical cemented ankle arthroplasty: A prospective series with long-term follow-up. Foot Ankle Int 1995; 16: 474–9.

e59. Huskisson EC: Measurement of pain. Lancet 1974; 2: 1127–31.

e60. Ware JE, Jr., Sherbourne CD: The MOS 36-item short-form health survey (SF-36). I. Conceptual framework and item selection. Med Care 1992; 30: 473–83.

e61. Buechel FF, Pappas MJ, Iorio LJ: New Jersey low contact stress total ankle replacement: Biomechanical rationale and review of 23 cementless cases. Foot Ankle 1988; 8: 279–90.

e62. Lee KB, Cho SG, Hur CI, Yoon TR: Perioperative complications of HINTEGRA total ankle replacement: Our initial 50 cases. Foot Ankle Int 2008; 29: 978–84.

e63. Lee KT, Lee YK, Young KW, et al.: Perioperative complications of the MOBILITY total ankle system: Comparison with the HINTEGRA total ankle system. J Orthop Sci 2010; 15: 317–22.

e64. Lee KT, Lee YK, Young KW, Kim JB, Seo YS: Perioperative complications and learning curve of the mobility total ankle system. Foot Ankle Int 2013; 34: 210–4.

e65. Myerson MS, Mroczek K: Perioperative complications of total ankle arthroplasty. Foot Ankle Int 2003; 24: 17–21.

e66. Schuberth JM, Patel S, Zarutsky E: Perioperative complications of the Agility total ankle replacement in 50 initial, consecutive cases. J Foot Ankle Surg 2006; 45: 139–46.

e67. Espinosa N, Walti M, Favre P, Snedeker JG: Misalignment of total ankle components can induce high joint contact pressures. J Bone Joint Surg Am 2010; 92: 1179–87.

e68. Fukuda T, Haddad SL, Ren Y, Zhang LQ: Impact of talar component rotation on contact pressure after total ankle arthroplasty: A cadaveric study. Foot Ankle Int 2010; 31: 404–11.

e69. Saltzman CL, Tochigi Y, Rudert MJ, McIff TE, Brown TD: The effect of agility ankle prosthesis misalignment on the peri-ankle ligaments. Clin Orthop Relat Res 2004; 424: 137–42.

e70. Tochigi Y, Rudert MJ, Brown TD, McIff TE, Saltzman CL: The effect of accuracy of implantation on range of movement of the Scandinavian total ankle replacement. J Bone Joint Surg Br 2005; 87: 736–40.

e71. Ali MS, Higgins GA, Mohamed M: Intermediate results of Buechel Pappas unconstrained uncemented total ankle replacement for osteoarthritis. J Foot Ankle Surg 2007; 46: 16–20.

e72. Alvine FG: The agility ankle replacement: The good and the bad. Foot Ankle Clin 2002; 7: 737–53.

e73. Anders H, Kaj K, Johan J, Urban R: The AES total ankle replacement: A mid-term analysis of 93 cases. Foot Ankle Surg 2010; 16: 61–4.

e74. Besse JL, Colombier JA, Asencio J, et al.: Total ankle arthroplasty in France. Orthop Traumatol Surg Res 2010; 96: 291–303.

e75. Bianchi A, Martinelli N, Sartorelli E, Malerba F: The Bologna-Oxford total ankle replacement: A mid-term follow-up study. J Bone Joint Surg Br 2012; 94: 793–8.

e76. Bonnin M, Judet T, Colombier JA, Buscayret F, Graveleau N, Piriou P: Midterm results of the Salto Total Ankle Prosthesis. Clin Orthop Relat Res 2004; 424: 6–18.

e77. Bonnin M, Gaudot F, Laurent JR, Ellis S, Colombier JA, Judet T: The salto total ankle arthroplasty: survivorship and analysis of failures at 7 to 11 years. Clin Orthop Relat Res 2011; 469: 225–36.

e78. Brunner S, Barg A, Knupp M, et al.: The Scandinavian total ankle replacement: Long-term, eleven to fifteen-year, survivorship analysis of the prosthesis in seventy-two consecutive patients. J Bone Joint Surg Am 2013; 95: 711–8.

e79. Buechel FF, Sr., Buechel FF, Jr., Pappas MJ: Twenty-year evaluation of cementless mobile-bearing total ankle replacements. Clin Orthop Relat Res 2004; 424: 19–26.

e80. Cenni F, Leardini A, Pieri M, et al.: Functional performance of a total ankle replacement: thorough assessment by combining gait and fluoroscopic analyses. Clin Biomech (Bristol, Avon) 2013; 28: 79–87.

e81. Criswell BJ, Douglas K, Naik R, Thomson AB: High revision and reoperation rates using the Agility Total Ankle System. Clin Orthop Relat Res 2012; 470: 1980–6.

e82. Dhawan R, Turner J, Sharma V, Nayak RK: Tri-Component, mobile bearing, total ankle replacement: Mid-term functional outcome and survival. J Foot Ankle Surg 2012; 51: 566–9.

e83. Doets HC, Brand R, Nelissen RG: Total ankle arthroplasty in inflammatory joint disease with use of two mobile-bearing designs. J Bone Joint Surg Am 2006; 88: 1272–84.

e84. Giannini S, Romagnoli M, O'Connor JJ, Malerba F, Leardini A: Total ankle replacement compatible with ligament function produces mobility, good clinical scores, and low complication rates: An early clinical assessment. Clin Orthop Relat Res 2010; 468: 2746–53.

e85. Giannini S, Romagnoli M, O'Connor JJ, et al.: Early clinical results of the BOX ankle replacement are satisfactory: A multicenter feasibility study of 158 ankles. J Foot Ankle Surg 2011; 50: 641–7.

e86. Henricson A, Skoog A, Carlsson A: The Swedish ankle arthroplasty register: An analysis of 531 arthroplasties between 1993 and 2005. Acta Orthop 2007; 78: 569–74.

e87. Henricson A, Nilsson JA, Carlsson A: 10-year survival of total ankle arthroplasties: A report on 780 cases from the Swedish ankle register. Acta Orthop 2011; 82: 655–9.

e88. Hosman AH, Mason RB, Hobbs T, Rothwell AG: A New Zealand national joint registry review of 202 total ankle replacements followed for up to 6 years. Acta Orthop 2007; 78: 584–91.

e89. Jensen NC, Kroner K: Total ankle joint replacement: A clinical follow up. Orthopedics 1992; 15: 236–9.

e90. Kitaoka HB, Patzer GL, Ilstrup DM, Wallrichs SL: Survivorship analysis of the Mayo total ankle arthroplasty. J Bone Joint Surg Am 1994; 76: 974–9.

e91. Kofoed H, Sorensen TS: Ankle arthroplasty for rheumatoid arthritis and osteoarthritis: Prospective long-term study of cemented replacements. J Bone Joint Surg Br 1998; 80: 328–32.

e92. Kofoed H, Lundberg-Jensen A: Ankle arthroplasty in patients younger and older than 50 years: A prospective series with long-term follow-up. Foot Ankle Int 1999; 20: 501–6.

e93. Kofoed H: Scandinavian total ankle replacement (STAR). Clin Orthop Relat Res 2004; 424: 73–9.

e94. Kokkonen A, Ikavalko M, Tiihonen R, Kautiainen H, Belt EA: High rate of osteolytic lesions in medium-term followup after the AES total ankle replacement. Foot Ankle Int 2011; 32: 168–75.

e95. Kraal T, van der Heide HJ, van Poppel BJ, Fiocco M, Nelissen RG, Doets HC: Long-term follow-up of mobile-bearing total ankle replacement in patients with inflammatory joint disease. Bone Joint J 2013; 95: 1656–61.

e96. Leardini A, O'Connor JJ, Catani F, Romagnoli M, Giannini S: Preliminary results of a biomechanics driven design of a total ankle prosthesis. J Foot Ankle Res 2008; 1: 8.

e97. Morgan SS, Brooke B, Harris NJ: Total ankle replacement by the ankle evolution system: Medium-term outcome. J Bone Joint Surg Br 2010; 92: 61–5.

e98. Nishikawa M, Tomita T, Fujii M, et al.: Total ankle replacement in rheumatoid arthritis. Int Orthop 2004; 28: 123–6.

e99. Nodzo SR, Miladore MP, Kaplan NB, Ritter CA: Short to midterm clinical and radiographic outcomes of the salto total ankle prosthesis. Foot Ankle Int 2014; 35: 22–9.

e100. Reuver JM, Dayerizadeh N, Burger B, Elmans L, Hoelen M, Tulp N: Total ankle replacement outcome in low volume centers: Short-term followup. Foot Ankle Int 2010; 31: 1064–8.

e101. San Giovanni TP, Keblish DJ, Thomas WH, Wilson MG: Eight-year results of a minimally constrained total ankle arthroplasty. Foot Ankle Int 2006; 27: 418–26.

e102. Schenk K, Lieske S, John M, et al.: Prospective study of a cementless, mobile-bearing, third generation total ankle prosthesis. Foot Ankle Int 2011; 32: 755–63.

e103. Schill S, Biehl C, Thabe H: Prothetische Versorgung des Sprunggelenks: Mittelfristige Ergebnisse nach Thompson-Richards- und STAR-Prothesen. Orthopade 1998; 27: 183–7.

e104. Schweitzer KM, Adams SB, Viens NA, et al.: Early prospective clinical results of a modern fixed-bearing total ankle arthroplasty. J Bone Joint Surg Am 2013; 95: 1002–11.

e105. Sproule JA, Chin T, Amin A, et al.: Clinical and radiographic outcomes of the mobility total ankle arthroplasty system: early results from a prospective multicenter study. Foot Ankle Int 2013; 34: 491–7.

e106. Summers JC, Bedi HS: Reoperation and patient satisfaction after the mobility total ankle arthroplasty. ANZ J Surg 2012; 83: 371–5.

e107. Trincat S, Kouyoumdjian P, Asencio G: Total ankle arthroplasty and coronal plane deformities. Orthop Traumatol Surg Res 2012; 98: 75–84.

e108. Wood PL, Deakin S: Total ankle replacement. The results in 200 ankles. J Bone Joint Surg Br 2003; 85: 334–41.

e109. Weber M, Bonnin M, Columbier JA, Judet T: Erste Ergebnisse der SALTO-Sprunggelenkendoprothese: Eine französische Multizenterstudie mit 115 Implantaten. Fuss Sprungg 2004; 2: 29–37.

e110. Willegger M, Trnka HJ, Schuh R: The HINTEGRA ankle arthroplasty: Intermediate term results of 16 consecutive ankles and a review on the current literature. Clin Res Foot Ankle 2013; 2: 1000124.

e111. Wood PL, Prem H, Sutton C: Total ankle replacement: Medium-term results in 200 Scandinavian total ankle replacements. J Bone Joint Surg Br 2008; 90: 605–9.

e112. Wood PL, Sutton C, Mishra V, Suneja R: A randomised, controlled trial of two mobile-bearing total ankle replacements. J Bone Joint Surg Br 2009; 91: 69–74.

e113. Thomason K, Eyres KS: A technique of fusion for failed total replacement of the ankle: Tibio-allograft-calcaneal fusion with a locked retrograde intramedullary nail. J Bone Joint Surg Br 2008; 90: 885–8.

e114. Kotnis R, Pasapula C, Anwar F, Cooke PH, Sharp RJ: The management of failed ankle replacement. J Bone Joint Surg Br 2006; 88: 1039–47.

e115. Espinosa N, Wirth SH: Sprunggelenkarthrodese nach gescheiterter Endoprothesenimplantation. Orthopade 2011; 40: 1008–17.

e116. Horisberger M, Paul J, Wiewiorski M, et al.: Commercially available trabecular metal ankle interpositional spacer for tibiotalocalcaneal arthrodesis secondary to severe bone loss of the ankle. J Foot Ankle Surg 2014; 53: 383–7.

e117. Wunschel M, Leichtle UG, Leichtle CI, et al.: Fusion following failed total ankle replacement. Clin Podiatr Med Surg 2013; 30: 187–98.

e118. Donnenwerth MP, Roukis TS: Tibio-talo-calcaneal arthrodesis with retrograde compression intramedullary nail fixation for salvage of failed total ankle replacement: A systematic review. Clin Podiatr Med Surg 2013; 30: 199–206.

e119. McCollum G, Myerson MS: Failure of the agility total ankle replacement system and the salvage options. Clin Podiatr Med Surg 2013; 30: 207–23.

e120. Deorio JK: Revision INBONE total ankle replacement. Clin Podiatr Med Surg 2013; 30: 225–36.

e121. Espinosa N, Wirth SH: Revision of the aseptic and septic total ankle replacement. Clin Podiatr Med Surg 2013; 30: 171–85.

eTABLE 1

Etiology of advanced ankle osteoarthritis, based on a selection of clinical and epidemiological studies*

Study	Study type	Patients (ankles)	Etiology of ankle osteoarthritis, % (absolute values)		
			Primary	Secondary	Posttraumatic
(e6)	RS, SC, clinical	45 (51)	25.5% (13)	54.9% (28) – Rheumatism: 54.9% (28)	19.6% (10)
(6)	PS, SC, clinical	684 (722)	9.5% (69)	11.4% (82)	79.1% (571)
(e7)	PS, SC, clinical	47 (50)	6.0% (3)	8.0% (4) – Rheumatism: 4.0% (2) – Tuberculosis: 2.0% (1) – Hemophilia: 2.0% (1)	86.0% (43) – State following fracture: 50.0% (25) – State following ligament injuries: 36.0% (18)
(e8)	PS, SC, clinical	49 (50)	16.0% (8)	18.0% (9) – Rheumatism: 14.0% (7) – Necrosis of the talus: 4.0% (2)	66.0% (33)
(e9)	PS, MC register, clinical	245 (257)	20.6% (53)	55.3% (142)	24.1% (62) – State following fracture: 22.1% (57) – State following ligament injuries: 1.9% (5)
(e10)	PS, SC, clinical	80 (83)	33.7% (28)	25.3% (21) – Rheumatism: 25.3% (21)	41.0% (34)
(e11)	RS, SC, clinical	111 (123)	52.8% (65)	18.7% (23)	28.5% (35)
(e12)	RS, SC, clinical	61 (62)	19.4% (12)	4.8% (3) – Clubfoot: 3.2% (2) – Postpolio: 1.6% (1)	75.8% (47)
(e13)	RS, SC, clinical	45 (52)	50.0% (26)	26.9% (14)	23.1% (12)
(e14)	RS, SC, clinical	126 (132)	28.8% (38)	25.0 (33) – Rheumatism: 23.5% (31) – Postinfection: 1.5% (2)	46.2% (61)
(e15)	PS, SC, clinical	43 (50)	54.0% (27)	32.0% (16)	14.0% (7)
(e16)	PS, SC, clinical	396 (404)	16.6% (67)	13.6% (55)	69.8% (282)
(e17)	PS, SC, clinical	80 (84)	25.0% (21)	19.0% (16) – Rheumatism: 17.9% (15) – Hemochromatosis: 1.2% (1)	56.0% (47) – State following fracture: 39.3% (33) – State following ligament injuries: 16.7% (14)
(e18)	PS, SC, clinical	82 (82)	34.2% (28)	13.4% (11)	52.4% (43)
(e19)	RS, SC, clinical	95 (100)	26.0% (26)	29.0% (29) – Rheumatism: 26.0% (26) – Postinfection: 2.0% (2) – Psoriasis: 1.0% (1)	45.0% (45)
(e20)	PS, SC, clinical	229 (229)	13.8% (32)	4.0% (9)	82.2% (188)
(e21)	PS, SC, clinical	106 (106)	52.8% (56)	20.8% (22)	26.4% (28)
(e22)	PS, SC, clinical	233 (240)	30.8% (74)	17.9% (43) – Rheumatism: 15.0% (36) – Hemochromatosis: 2.9% (7)	51.3% (123)
(3)	PS, SC, epidemiological	639 (639)	7.2% (46)	23.2% (148) – Rheumatism: 11.9% (76) – Neuropathy: 4.9% (31) – Hemophilia: 1.9% (12) – Postinfection: 1.6% (10) – Gout: 0.8% (5)	69.6% (445) – State following fracture: 46.6% (298) – State following ligament injuries: 19.7% (126) – Traumatic osteochondral lesions: 3.3% (21)
(7)	PS, MC, clinical	593 (593)	26.5% (157)	15.3% (91)	58.2% (345)
(e23)	RS, SC, clinical	100 (100)	30.0% (30)	44.0% (44)	26.0% (26)
(e24)	RS, MC, clinical	478 (489)	15.3% (75)	25.8% (126)	58.9% (228)
(e25)	PS, MC register, clinical	515 (515)	19.2% (99)	59.2% (305)	21.6% (111)
(e26)	RS, SC, clinical	303 (306)	25.2% (77)	10.1% (31)	64.7% (198)
(e27)	RS, SC, clinical	103 (103)	71.8% (74)	18.5% (19)	9.7% (10)

Study	Study type	Patients (ankles)	Etiology of ankle osteoarthritis, % (absolute values)		
			Primary	Secondary	Posttraumatic
(e28)	PS, SC, clinical	65 (68)	13.2% (9)	16.2% (11) – Rheumatism: 7.4% (5) – Hemochromatosis: 4.4% (3) – Psoriasis: 1.5% (1) – Lupus erythematosus: 1.5% (1) – Sclerodermia: 1.5% (1)	70.6% (48) – State following fracture: 60.3% (41) – State following ligament injuries: 10.3% (7)
(e3)	RS, SC, epidemiological	390 (406)	8.9% (36)	12.8% (52) – Rheumatism: 5.4% (22) – Hemochromatosis: 2.7% (11) – Hemophilia: 1.5% (6) – Clubfoot: 1.0% (4) – Avascular necrosis of the talus: 0.7% (3) – Osteochondral lesions: 0.7% (3) – Postinfection: 0.7% (3)	78.3% (318) – State following fracture: 62.3% (253) – State following ligament injuries: 16.0% (65)
(e29)	PS, SC, clinical	66 (66)	0.0% (0)	10.6% (7) – Necrosis of the talus: 4.5% (3) – Hemophilia: 3.0% (2) – Rheumatism: 1.5% (1) – Hemochromatosis: 1.5% (1)	89.4% (59) – State following fracture: 72.7% (48) – State following ligament injuries: 16.7% (11)
(e4)	RS, SC, clinical	226 (233)	5.6% (13)	23.2% (54) – Flatfoot: 8.2% (19) – Rheumatism: 7.3% (17) – Clubfoot: 3.4% (8) – Osteochondral lesion: 1.7% (2) – Postinfection: 1.3% (1.3) – Charcot–Marie–Tooth disease: 0.9% (2) – Hemophilia: 0.4% (1)	71.2% (166) – State following fracture: 59.2% (138) – State following ligament injuries: 12.0% (28)
(e30)	PS, SC, clinical	96 (100)	64.0% (64)	27.0% (27) – Rheumatism: 27.0% (27)	9.0% (9) – State following fracture: 9.0% (9)
(e31)	RS, SC, clinical	90 (99)	40.4% (40)	12.1% (12)	47.5% (47)
Total		6218 (6389)	21.5% (1373)	22.6% (1441)	56.0% (3575)

*Clinical (total ankle replacement) and epidemiological (etiology of ankle osteoarthritis) studies with at least 50 patients were included.
MC: multicenter; PS: prospective; RS: retrospective; SC: single-center

eTABLE 2

Classification of current ankle implant types

	Surgical access	Inlay type	Replaced surfaces	Internal implant surfaces	Inlay materials	Sulcus type	Surface morphology
AAA	Anterior	Mobile	Superior	HA	UHMWPE	None	Trapezoidal
AES	Anterior	Mobile	Superior	HA	UHMWPE	Deep	Trapezoidal
Agility	Anterior	Fixed	Superior/medial/ lateral	Titanium	UHMWPE	None	Trapezoidal
BOX	Anterior	Mobile	Superior	HA	UHMWPE	Normal	Ellipsoidal
Buechel-Pappas	Anterior	Mobile	Superior	Titanium	UHMWPE	Deep	Ellipsoidal
ESKA	Lateral/medial	Fixed	Superior	Titanium	UHMWPE	Normal	Ellipsoidal
INBONE	Anterior	Fixed	Superior	Titanium	UHMWPE	Normal	Spheroidal
HINTEGRA	Anterior	Mobile	Superior/medial	HA	UHMWPE	None	Conical
Mobility	Anterior	Mobile	Superior	Titanium	UHMWPE	Deep	Trapezoidal
Ramses	Anterior	Mobile	Superior	HA	UHMWPE	None	Ellipsoidal
Salto	Anterior	Mobile	Superior/medial	HA	UHMWPE	Normal	Conical
STAR	Anterior	Mobile	Superior	HA	UHMWPE	None	Cylindrical
TNK	Anterior	Fixed	Superior	HA	UHMWPE, ceramic	None	Cylindrical
TM Total Ankle	Lateral	Fixed	Superior	Porous metal	Highly cross-linked UHMWPE	None	Conical

AAA: Alpha Ankle Arthroplasty; AES: Ankle Evolutive System; BOX: Bologna–Oxford; HA: hydroxyapatite; STAR: Scandinavian Total Ankle Replacement; TM: Trabecular Metal; UHMWPE: ultra-high-molecular-weight polyethylene

eTABLE 3

Additional procedures in patients with concomitant valgus or varus hindfoot deformity

Patients with valgus hindfoot deformity	
Supramalleolar valgus deformity	Supramalleolar tibial osteotomy: – Medial closing tibial osteotomy (e43–e45)
Isolated valgus defective heel position	Corrective calcaneal osteotomy: – Medial sliding calcaneal osteotomy (e46)
Flexible pes planovalgus et abductus deformity	Corrective calcaneal osteotomy: – Lateral sliding calcaneal osteotomy (e47) Tendon transfer: – Flexor digitorum longus to tibialis posterior (e48)
Rigid pes planovalgus et abductus deformity	Corrective arthrodesis of the hindfoot:* – Subtalar arthrodesis (e49) – Triple arthrodesis with or without calcaneocuboidal joint (e50)
Medial instability	Medial ligament stabilization: – Anatomical reconstruction with transosseous sutures (e51) – Reconstruction with tendon autograft (e52)
Patients with varus hindfoot deformity	
Supramalleolar varus deformity	Supramalleolar tibial osteotomy: – Medial opening tibial osteotomy (with supramelleolar deformity <10°) (e44, e45, e53) – Lateral closing tibial osteotomy (with supramelleolar deformity >10°) (e44, e45, e53)
Flexible varus abnormal heel position	Corrective calcaneal osteotomy: – Dwyer calcaneal osteotomy (e54) – Z-shaped calcaneal osteotomy (e55)
Rigid inframalleolar varus alignment	Corrective arthrodesis of the hindfoot: – Subtalar arthrodesis (e49)
Lateral instability	Lateral ligament stabilization: – Anatomical reconstruction with transosseous stitches (e56) – Reconstruction with tendon autograft (e57)

*Depends on extent of deformity and degenerative changes

eTABLE 4

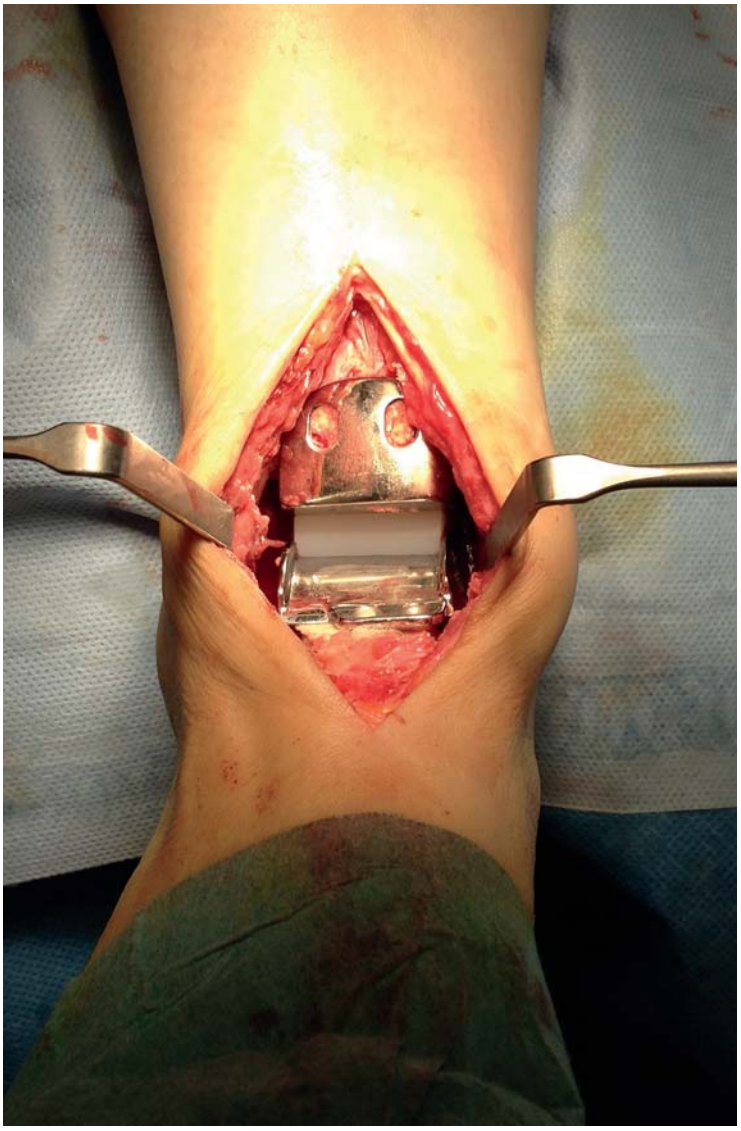
Clinical outcomes following total ankle replacement: probability of survival of implant components and postoperative range of ankle motion*

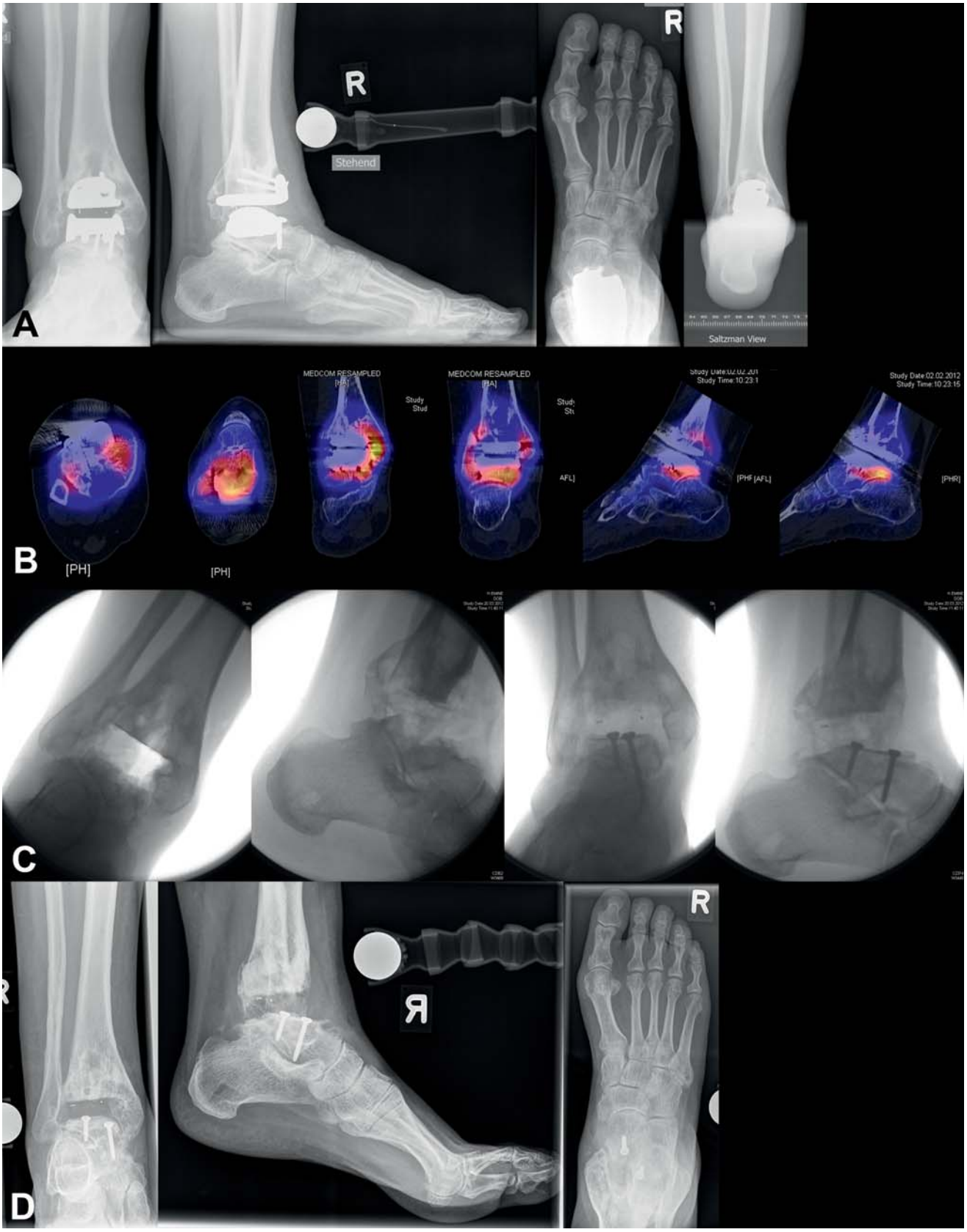
Study	Study type	Implant type	No. of implants	Probability of survival of implant components	Mean follow-up time	Postoperative range of motion
(e71)	RS, SC	Buechel–Pappas	35	97% after 5 years	5 years (3 to 150 months)	N/A
(e72)	RS, SC	Agility	207	76% after 9 years	N/A	N/A
(e73)	RS, SC	AES	93	90% after 5 years	42 months (13 to 73 months)	N/A
(e6)	RS, SC	STAR	51	70% after 5 years	52 months (36 to 97 months)	Total 28° (10 to 55°)
(22)	RS, SC	HINTEGRA	123	93% after 6 years	67.7 ± 27.0 months (29 to 126 months)	Total 35.3°± 8.1°
(e34)	PS, SC	HINTEGRA	52	91% after 5 years, 78% after 8 years	5 years (2 to 10 years)	Total 38°± 9°
(6)	PS, SC	HINTEGRA	722	94% after 5 years, 84% after 10 years	6.3 ± 2.9 years (2 to 12.2 years)	N/A
(e74)	RS, MC	Salto (388), AES (173), HINTEGRA (22), STAR (9)	592	88% after 71 months	Min. 1 year	N/A
(e75)	PS, SC	BOX	62	91.9% after 42.5 months	42.5 months (24 to 71 months)	DF 8.4° ± 4.8° (0 to 20°); PF 17.1° ± 8.3° (0 to 30°)
(e76)	RS, SC	Salto	98	98% after 5 years	35 months (24 to 68 months)	Total 28.3° ± 7°
(e77)	RS, SC	Salto	98	85% after 10 years	8.9 years (6.8 to 11 years)	DF 8.6° ± 5.3° (−5 to 20°); PF 18.1° ± 7.8° (5 to 40°)
(e78)	PS, SC	STAR	77	70.7 after 10 years, 45.6% after 14 years	12.4 years (10.8 to 14.9 years)	Total 22.8°±3.5°
(e8)	PS, SC	Buechel–Pappas	50	93.5% after 10 years	5 years (2 to 10 years)	Total 28° (12 to 46°)
(e79)	PS, SC	Buechel–Pappas (normal sulcus 40; deep sulcus 75)	115	74.2% (normal sulcus) after 20 years, 92% (deep Sulkus) after 12 years	12 years (2 to 10 years, normal sulcus), 5 years (2 to 12 years, deep sulcus)	Total 25° (10 to 47°, normal sulcus), total 29° (10 to 50°, deep sulcus)
(e80)	PS, SC	BOX	20	N/A	12 months (7 to 14 months)	Total 28.8° ± 11.3° (10 to 50°)
(e81)	RS, SC	Agility	42	62% after 9 years	8 years (0.5 to 11 years)	
(e82)	RS, SC	Buechel–Pappas	30	87.6% after 5 years	5.1 ± 4 years (1 to 13 years)	DF 5°; PF 30°
(e83)	PS, SC	LCS (19), Buechel–Pappas (74)	93	84% after 8 years	7.2 years (0.4 to 16.3 years)	DF 7.1° (5.8 to 8.4°); PF 24.8° (22.6 to 27.2°)
(e9)	PS, MC	STAR (216), TPR (32), HINTEGRA (6), AES (3)	257	89% after 5 years, 76% after 10 years	4 years (5 days to 12 years)	N/A
(e84)	PS, MC	BOX	51	97.2% after 3 years	30 months (24 to 48 months)	Total 27.4° (16 to 53°)
(e85)	PS, MC	BOX	158	96.1% after 4 years	17 months (6 to 48 months)	Total 26.5° (14 to 53°)
(e86)	PS, MC	STAR (318), Buechel–Pappas (92), AES (69), HINTEGRA (29), Mobility (23)	531	78% after 5 years, 62% after 10 years	1 to 11 years	N/A

Study	Study type	Implant type	No. of implants	Probability of survival of implant components	Mean follow-up time	Postoperative range of motion
(e87)	PS, MC	STAR (322), Mobility (132), AES (115), Buechel–Pappas (109), CCI (66), HINTEGRA (36)	780	81% after 5 years, 69% after 10 years	10 years	N/A
(e11)	RS, SC	STAR	123	86% (patients with preoperative deformity up to 10°) and 75% (patients with preoperative deformity 10 to 30°) after 5 years	4 years (2 to 8 years)	N/A
(e88)	PS, MC	Agility (117), STAR (45), Mobility (29), Ramses (11)	202	86% after 5 years	28 to 75 months	N/A
(e12)	RS, SC	Agility	65	91% after 1 year, 70% after 3 years, 67% after 5 years	3.3 years (2 to 5.9 years)	N/A
(e89)	RS, SC	TPR	33	85% after 10 years	10 to 23 years	N/A
(e13)	RS, SC	STAR	52	90% after 5 years, 84% after 8 years	80 months (60 to 110 months)	Total 23° ± 12° (0 to 55°)
(e90)	RS, SC	Mayo	204	79% after 5 years, 65% after 10 years, 61% after 15 years	9 years (2 to 17 years)	k. A.
(e14)	RS, SC	Agility	132	86% after 9 years, 63% after 11 years	9 years	DF 0° (−24 to 16°); PF 19° (−1 to 36°)
(e58)	PS, SC	STAR	28	70% after 12 years	1 to 12 years	N/A
(e91)	PS, SC	STAR	52	72.7% (primary osteoarthritis) and 75.5% (rheumatoid arthritis) after 14 years	9 years (6 to 14 years)	N/A
(e92)	PS, SC	STAR	100	85.7% (patients under 50) and 91.6% (patients over 50) after 5 years, 75% (patients under 50) and 80.6% (patients over 50) after 10 years	6.8 years (1 to 15 years)	N/A
(e93)	PS, SC	STAR (33 cemented, 25 uncemented)	58	70% (cemented) and 95.4% (uncemented) after 12 years	9.4 ± 2.7 years	N/A
(e94)	PS, SC	AES	38	79% after 2 years	28 months (2 to 70 months)	N/A
(e95)	PS, SC	LCS (19), Buechel–Pappas (74)	93	80% after 15 years	14.8 years (10.7 to 22.8 years)	N/A
(e96)	PS, MC	BOX	189	97% after 4 years	21 months	Total 14 to 53°
(e16)	PS, SC	INBONE (211), STAR (122), Salto-Talaris (71)	404	90% and 97.6% after 3.2 years with and without arthrodesis of the hindfoot	3.2 years (2 to 6 years)	N/A
(e17)	PS, SC	STAR	84	96% after 5 years, 90% after 10 years	9.1 years (2.6 to 11 years)	DF 4.5°; PF 34.7°
(e97)	RS, SC	AES	38	94.7% after 6 years	57.8 months (48 to 80 months)	N/A
(e98)	RS, SC	TNK	27	77% after 14.1 years	72 months (15 to 169 months)	DF 7.5° (0 to 20°); PF 8.5° (−10 to 20°)
(e99)	RS, SC	Salto	75	98% after 3.6 years	43 months (27 to 73 months)	DF 8.7° ± 5.6°; PF 29° ± 7°
(21)	RS, MC	Salto (91), HINTEGRA (39), AES (20), Coppelia (17), STAR (11), Ramses (4), Akile (1)	183	86% (high-volume sites 88.4%; low-volume sites 84.9%) after 5 years	39 ± 29 months (6 to 132 months)	N/A

Study	Study type	Implant type	No. of implants	Probability of survival of implant components	Mean follow-up time	Postoperative range of motion
(e100)	RS, MC	STAR	59	88% after 3 years	36 months (12 to 65 months)	DF 10.2° ± 6.3°; PF 11.3° ± 7.9°
(e22)	PS, SC	Mobility	240	97.7% after 4 years	32.8 ± 15.3 months (12 to 63 months)	DF 8.3° ± 5.3°; PF 13.6° ± 6.4°
(e101)	RS, SC	Buechel–Pappas	28	93% after 8.3 years	8.3 years (5 to 12.2 years)	Total 23° (8 to 40°)
(e102)	RS, SC	Salto	401	86.6% (all patients), 85.1% (posttraumatic osteoarthritis), 95.6% (rheumatoid arthritis), 87.9% (patients under 55) after 5 years	29 months (1 to 84 months)	Total 33.1° ± 13.6°
(e103)	PS, SC	TPR (20), STAR (19)	39	87% (TPR) after 12 years, 94.3% (STAR) after 6 years	8.6 years (TPR: 3 to 13 years), 3.1 years (STAR: 1 to 6 years)	Total (TPR) 37°. Total (STAR) 33.5°
(e104)	PS, SC	Salto Talaris	75	96% after 2.8 years	2.8 years (2 to 4.5 years)	N/A
(e25)	PS, MC	AES (298), STAR (217)	515	83% after 5 years	3.2 years (0.1 to 9.6 years)	N/A
(e26)	RS, SC	Agility	306	80% (89% in patients over 54) after 5 years	33 ± 18 months (4 to 75 months)	N/A
(e105)	PS, MC	Mobility	88	89.6% after 3 years, 88.4% after 4 years	40 months (30 to 60 months)	N/A
(e106)	RS, SC	Mobility	58	84% after 4 years	32 months (14 to 49 months)	N/A
(e107)	RS, SC	AES (16), Salto (4), New-Jersey (1)	21	91% after 3 years, 57% after 5 years	38 ± 26 months	N/A
(e108)	PS, SC	STAR	200	92.7% after 5 years	46 months (24 to 101 months)	N/A
(e109)	RS, MC	Salto	109	97.5% after 2 years	21.7 months (12 to 65 months)	Total 32°
(e110)	RS, SC	HINTEGRA	16	66.7% after 5 years	61.8 months (7 to 116 months)	Total 23.7° (12.0 to 47.5°)
(e111)	PS, SC	STAR	200	93.3% after 5 years, 80.3% after 10 years	88 months (60 to 156 months)	N/A
(e112)	PS, SC	Buechel–Pappas (100), STAR (100)	200	79% (Buechel–Pappas) and 95% (STAR) after 6 years	Min. 36 months	N/A
(e30)	PS, SC	Mobility	100	97% after 3 years, 93.6% after 4 years	43 months (4 to 63 months)	DF 7.5° (−5 to 22°), PF 14° (1 to 41°)

*All available clinical studies (total ankle replacement) were included.
AES: Ankle Evolutive System; BOX: Bologna–Oxford; DF: dorsiflexion; N/A: information not available; LCS: low-contact stress; MC: multicenter; PF: plantar flexion; PS: prospective; RS: retrospective; STAR: Scandinavian Total Ankle Replacement; TPR: Thomson, Prichard and Richard; SC: single-center

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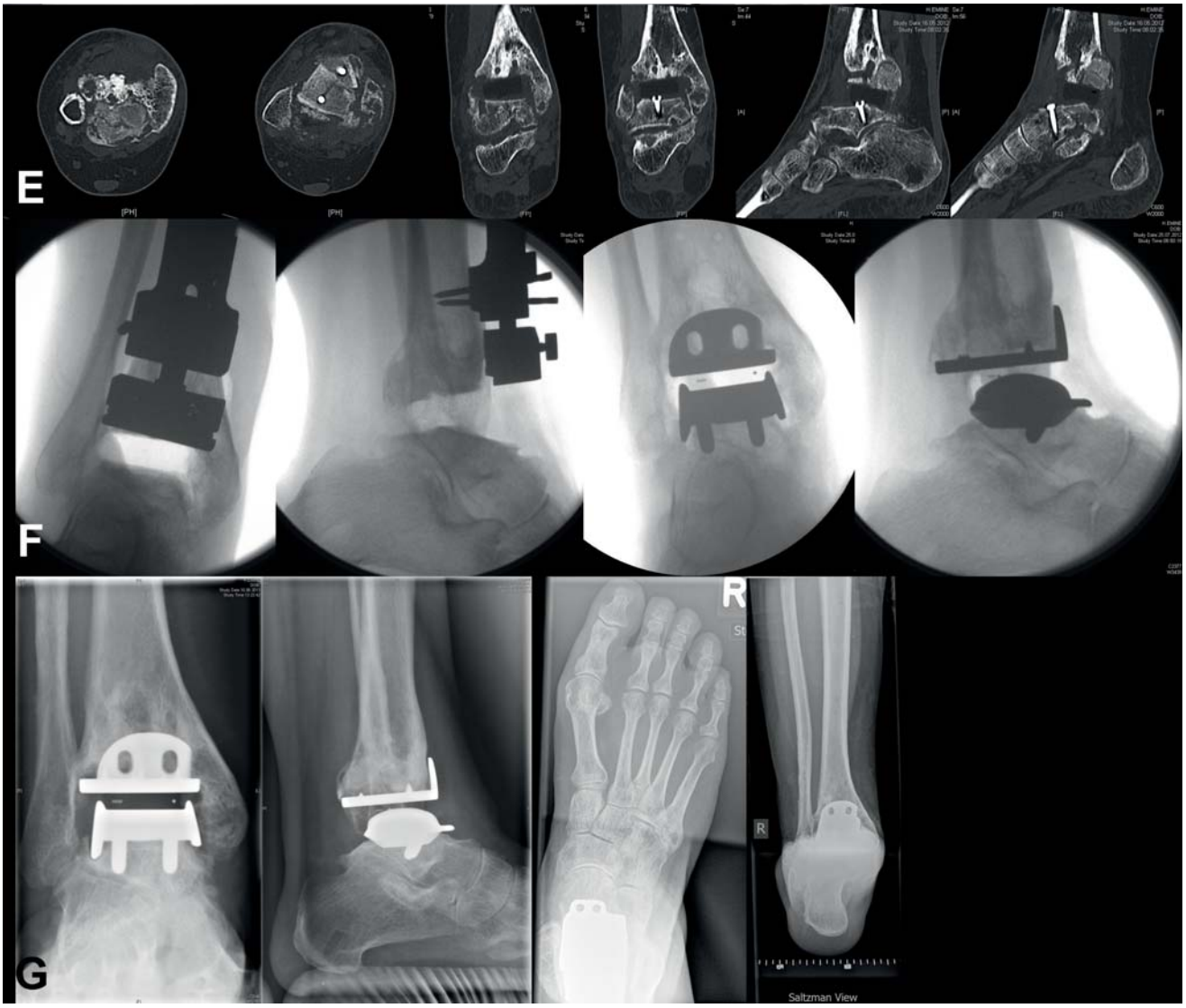
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